L. Bjermer

The nose as an air conditioner for the lower airways

Authors' affiliations:
L. Bjermer, Department of Lung Medicine, University Hospital, Trondheim, Norway

Correspondence to:
Leif Bjermer MD
Department of Lung Medicine
University Hospital
N-7006 Trondheim
Norway

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Introduction

The nose has an important frontier role protecting the lower airways from unconditioned air. In resting and light exercise situations, the majority of individuals breathe all air through the nose. However, with increased exercise a substantial part of the inhaled air also passes through and is being conditioned by the nose (1–3). At rest as well as during exercise it seems to be advantageous to have a significant portion of the air conditioned by the nose. In patients with asthma, improvement of nasal breathing contributes to an overall better disease control, with reduced nocturnal asthma as one important outcome (4). However, also in healthy subjects, nasal contribution seems important for optimal physical performance, measured as oxygen consumption related to workload and ventilation (5, 6). The importance of the nose can be divided into three important areas: 1) filtration of the air for allergens and polluting dust; 2) humidification and heat exchange; 3) contribution to the regulation of the ventilation and perfusion in the lower airways.

The nose as a filter for inhaled air

The protective effect by the nose has been known and studied for more than a century (7). The shape of the nose with nostril hair induces air turbulence, which facilitates the dust particles' attachment to the nasal mucosa, thereby protecting the lower airways from exposure. From deposition studies it is known that a surprisingly large fraction of the inspired naturally occurring dust is either taken out of the air during respiratory nasal passage or is breathed in and out without respiratory deposition (for review see (8)). Several factors are important for this filtering capacity.

The air is speeded to a high linear velocity after the narrow entrance of the nose and thereafter undergoing a bend, whereafter the airflow is reduced. In the main nasal passage the airflow is lower, passing a large mucosal surface. This mucosal surface is quickly adjustable in order to attach and remove particles through mucociliary clearance and to provide heat and humidity to the inspired air. The number of dust particles that will attach to the mucosal surface depends on several factors such as physical size, shape, density and hygroscopicity. If the particle is hygroscopic it will absorb water while it is passing through the nose, and thereby increase in size. The total mass deposition of inhaled particles in an urban aerosol during nose breathing when the humidity is increased from 0% to 99% will increase from 0.54 to 0.70 while the alveolar deposition will decrease by 20% (9). Another important factor is the speed and the nature of the passage through the nasal cavity. The linear flow through the first passage of the nose ending in a bend results in a turbulent flow that facilitates attachment of particles in the posterior part of the nasal cavity. The higher the initial flow the greater the turbulence. Moreover, the linear velocity is dependent on the breathing frequency and the resistance (narrowness) in the anterior part of the nose. Thus, the faster one inhales the greater the turbulence and impaction of particles in the mucosa. Finally, the particles with electrical charge or a higher gravity will be more prone to attach.

When breathing through the nose even particles with low mass diameter are effectively removed. This was shown earlier by Hounam et al. (10, 11). They found that 15–20% of particles with 2 μm diameter were deposited in the nose at a breathing rate of 25 L/min, while 45% were removed at 50 L/min and 60% at 75 L/min. They found no particles over 5 μm penetrating the nose at 50 L/min. However, the ability to absorb and filter particles by the nose may vary considerably between individuals. It is also known that children compared to adults have a lower degree of nasal deposition (12). Studies are needed in order to find out whether differences in nose size and function have impact on disease susceptibility.

Oronasal distribution and disease susceptibility

As large variations exist in nose size and function between individuals, there are perhaps even larger variations in degree of nose versus mouth breathing pattern (1, 13). Oral breathing induces a higher degree of bronchoconstriction after exercise than nasal breathing in asthmatic subjects (14), and oronasal breathing reduces the obstructive response to SO_2 exposure in susceptible individuals (15). As early as 1935, Lehman (16) reported that the risk of developing silicosis in mine workers was correlated to the degree of nasal breathing and the capacity by the nose to act as a dust filter. Thus, it would be plausible to believe that the same argument can be applied to allergen exposure and the risk of developing lower airway sensitization in those who are forced to mouth-breathing due to increased resistance in the nose. Indeed, it has been shown that asthmatics with concomitant rhinitis often have an asthma that is difficult to control (17, 18). Moreover, patients with rhinitis with or without asthma symptoms often have bronchial hyperresponsiveness, and this tends to become worse when the rhinitis is worsening (19).

Humidification and heat exchange

Acute and chronic hyperventilation with dry and cold air is associated with an increased risk of developing airway hyperresponsiveness and asthma. Cross-country skiers, exercising for longer periods in cold dry climates, have a higher risk of developing disease than those exercising in more humid, less cold areas (29). Whether or not it is the dry or cold component that is associated with the highest risk has been under debate. Cooling of the circulation in the airway mucosa leads to bronchial constriction. Moreover, the transient shift from cold to warm environments after hyperventilation leads to a rebound hyperemia and bronchoconstriction (21, 22). This phenomenon can be inhibited partly by controlled breathing and a slow adjustment to shifts in temperature (21). The nose has an astonishing capacity to heat the air rapidly, avoiding cold air reaching the lower airways. Even in such very cold temperatures as −18°C and a high minute ventilation of 100 L/min, the air temperature at segmental bronchial level is more than +20°C. Therefore, it seems highly unlikely that those cold components solely can cause great harm to the airways. However, the lower the temperature the lower the water content in the air. At temperatures of −20°C and lower, the content of water in the inspired air is practically zero. Therefore, inhalation of cold air almost always means concomitant inhalation of dry air. Dry air inhalation with and without concomitant cold exposure is also known to provoke bronchial constriction in normals and in asthmatics (23). Thus, the humidification of the inspired air is probably the most important role of the nose. When the person is breathing mainly through the nose, the nose acts as a humidity and heat exchanger, adding warmth and moisture to the inspired air and extracting humidity and temperature during exhalation.

A normal active adult inspires 14 000 L of air during 24 h. This amount of air will contain 680 g of water after it has been inspired. This amount of water will represent approximately one-fifth of the normal total water intake and half of the daily urinary output. If the subject inspires dry air at 17°C it will require 400 Kcal to humidify and 80 Kcal to warm the air. Provided that the majority of air is exhaled through the nose, about one-third of heat and water can be extracted from the air.

Thus, humidification of the air is also a fairly energy-consuming activity in normal situations. This becomes even more obvious in situations with hard and long-standing exercise in cold and dry climatic conditions. In athletes performing strenuous exercise in cold air, an average breathing volume of 100 L/min requires substantial stress for the airways.

In a temperature of $-15°C$ the humidity in the air will be almost zero. With a ventilation of 100 L/min, 290 g water is needed for moisturing equal to 171 Kcal energy. In addition it will take additional 98 Kcal to heat the inhaled air. Normally, also in situations with high minute volume up to 100 L/min, nearly 35% of the air is inspired and expired through the nose (13). Moreover, during extreme conditions the nose can adjust the mucosal blood flow so that warming and humidification as well as extracting heat and water from the expired air becomes even more effective. While at rest approximately one-third of the water and heat content are preserved when passing through the nose cavity, possibly increasing to 50% in colder conditions. Thus, also in situations with only a third portion of air passing through the nose, the air conditioned by the nose may be enough to protect the proximal airways from extreme stress caused by the cold and dry air provided by oral breathing. Hogman has shown, in a rabbit model, that hyperventilation of dry air through the mouth can subtract enough water from the airway mucosa to cause shrinkage and morphological changes in the respiratory epithelium (24). Thus, the nose has a crucial role in humidification and heating the inspired air and thereby protecting the lower airways. In addition, the nose also preserves some of the energy by extracting heat and water from the expired air.

The regulation of the heat and humidification capacity is due partly to a local neural reflex in the nasal mucosa. Instillation of cold dry air in one nostril gives rhinorrhea in both nostrils, an effect that is effectively blocked by local anesthesia (25). However, this function also seems to be related to stimulus outside the nose, as heating and cooling of body surface also affects the heat and humidification capacity of the nose (26). Moreover, Leclerc et al. (27) found an association between the nasal resistance cycles and axillary sweat production, indicating that nasal mucosal blood flow and function is influenced by central regulatory mechanisms (27). It is plausible to believe that the size of the nose has some impact on the ability to handle extreme cold climates. A large nasal cavity would theoretically be advantageous in cold-dry or hot-dry climate areas. This is supported by anthropological studies on skulls derived from Eskimos and Fuegian tribes; both living in harsh environmental conditions, they had a higher nose cavity compared to population groups living in more temperate regions (28). Croigner et al. found a similar pattern of climate association studying skulls from population groups in European and Mediterranean areas, with hot and dry climate being associated with a higher "nasal index" (29). However, the most impressive climate adjustments are seen in other animal species. The camel, as one example, has a well-developed ability to extract heat and water from the exhaled air (30), as in extreme conditions more than 75% of the water in the expired air can be extracted when passing through the camel's nose (31).

The role of the nose, contributing to the regulation of the ventilation and perfusion of the lower airways

Heating and humidification may not be the only way the nose is contributing to the quality of the inspired air. Even in situations when the individuals are inspiring conditioned air, nasal breathing seems to be advantageous compared to using only the mouth.

The endogenous production of nitric oxide (NO) has attracted much attention during recent years. Nitric oxide is produced as a highly reactive radical when the semi-essential amino acid L-arginine is converted to L-citrulline. The production of NO is divided basically into major pathways. A considerable part of the basal NO production seems to take part in the upper airways, especially in the paranasal sinuses (32). While the basal level of NO in exhaled air from the lower airways usually is less then 10 ppb, the levels in the nasal cavity are usually 100 times higher. In the nasal sinuses the NO production is regulated by the inducible nitric synthase (iNOS), whereas in the lower airways it is regulated by the constitutive nitric oxide synthase (cNOS). There is also a variable production related to inflammatory processes in the respiratory epithelium, where NO is formed by iNOS.

The role of NO in the airways is not quite clear. However, NO has a vaso- and bronchodilator capacity and the inhalation of NO, even in very low concentrations, has been shown to reduce the resistance in the lower airways. It has been shown that administration into the lower airways of NO sampled from the nasal cavity is sufficient to improve oxygenation in healthy subjects and in intubated patients (33). Although NO has a direct action on bronchial tone as well as on the blood perfusion only in the ventilated areas, NO could contribute to an improved match between perfusion and ventilation in the lung. It has been shown that NO delivered to patients with COPD and latent cardiac incompensation improves their cardiopulmonary function when NO is supplemented to oxygen during exercise (34). The same phenomenon has been shown in healthy controls.

Nose breathing, compared to mouth breathing, provides a more economical work pattern with less oxygen consumption (6) and reduced ventilation (35) on a defined workload. Therefore, nose breathing compared to mouth breathing is not only recommended for humidification and temperature-regulative purposes; nose breathing also contributes, with NO as one example, to better function in the complete respiratory system. This could have therapeutic implications. Perhaps we should focus more upon breathing patterns as a mean for patients with obstructive lung disease to better master their disease. In eastern theories, they have a tradition of looking at breathing patterns as a way of achieving a better control over both mind and body. It has also been shown, in a randomized trial, that asthma patients benefit from a controlled breathing pattern, in yoga terms known as "pranayama" (36).

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